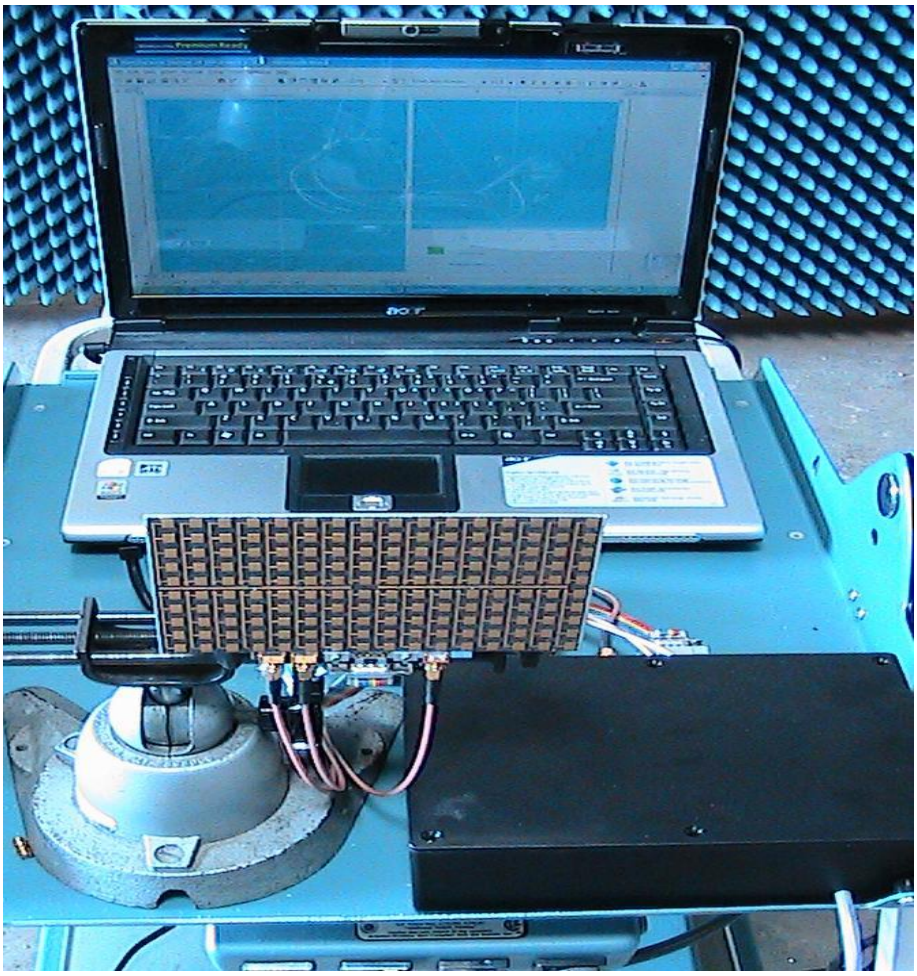
24GHz FMCW Radar User Manual



FMCW front-end transmits period liner triangle wave in frequency-time plane. It swept band B at time T (slop k=+/-B/T). Return signal reflected by target has time delay td (td=2R/C) with Doppler frequency fd. The coherent output, beat signal, is equal to fb=(2B/CT)R+/-fd. Back end detect fb by DSP in +/-slop period, Range and velocity of target is tested with amplitude. Azimuth or elevation angle could be obtained by mono-pulse antenna or beam forming technology. Mechanical scanning, usually in azimuth direction, is used for wide scanning range. Radar data will generate radar map on Host PC screen.

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1. Application Fields

This radar is typical used to detect vehicle with max distance 200m or detect human inside 50m. The range resolution is 1 meter or less (design value is 0.75m). Attached Fig 1 is the test photo for vehicle in 120meters. There is a big truck in 44 meter, but is at adjacent lane, which is at least 4meter long. The radar map shows exactly 1target in 120m, and 2 targets in 44m and 47m. The radar data will provide target or targets information as: Amplitude, Range, Velocity, Azimuth angle by mono-pulse, and time gap for next time see target again with distance at that time. The last 10 pages radar data is stored in DSP memory and can be send out thru Ethernet cable. The host computer with radar map code will operate radar and display radar map.

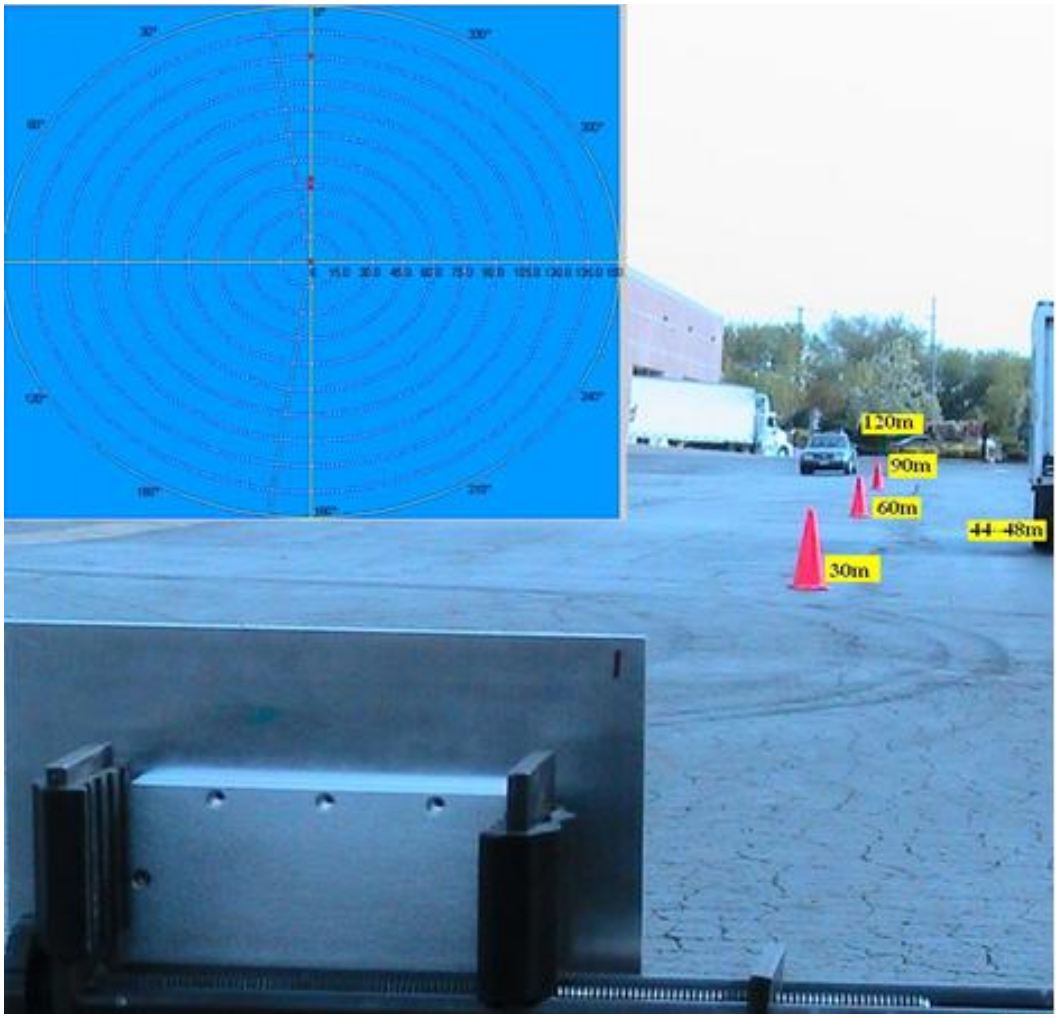

Fig 1 Typical Application of 24GHz FMCW Radar

2. Basic Parts of 24GHz FMCW Sensor/Radar

24GHz FMCW radar is formed by front-end, back-end, connect cable, and optional host PC. Front-end has dual antennas and transceiver. Transceiver has FMCW TX, which is controlled by back-end to generate FMCW signals. It shares 1 antenna with 1 RX CH. There are 2 RXs to get mono-pulse function in Azimuth plane. Back-end has TX signal controller to generate linearity FMCW signal. It has 2 CH ADC to process mono-pulse signal if digit format. Back-end output radar data thru USB interface to main DSP (as FMCW sensor) or to host computer (as FMCW radar). Host computer must have radar map code to run the radar. Figure 2 is the photo for main parts. Table 1 lists main parts and key function.

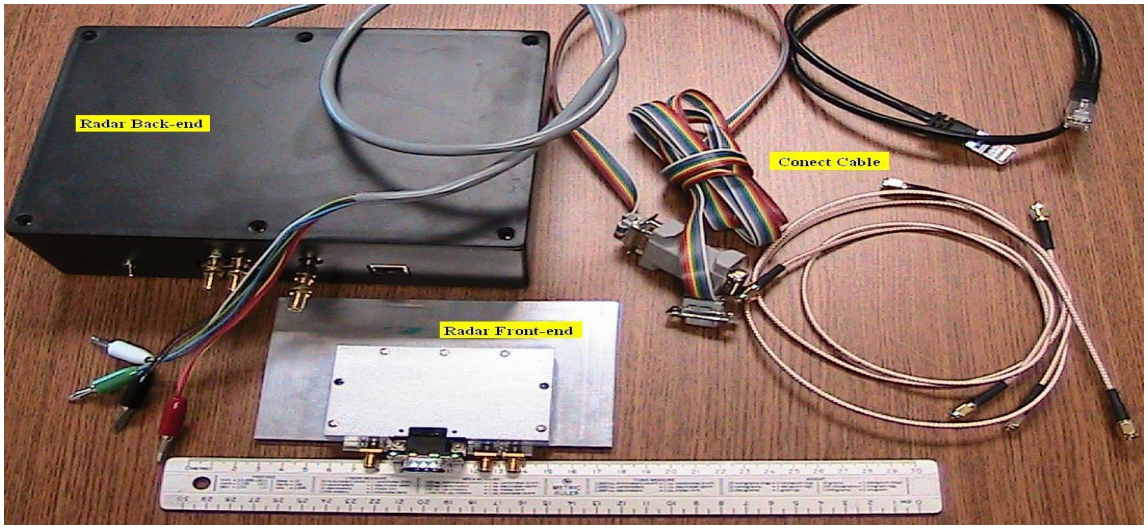

Fig 2 Main Parts

Name	Main sub unit	Key function
Front-end	Patch array antenna for TX and RX	Transmit 24.125GH, 200MHz band FMCW signal to target, receive return signal
	24GHz Transceiver with 2CH RX	TX send 8dBm FMCW signal controlled by DSP 2CH RX send mix 1.25MHz beat signal to back-end
Back-end	TX controller	Send FMCE refer to TX, get accuracy frequency, band and linearity
	RX DSP unite	ADC and FFT convert for DSP
	Interface	Radar data ready to host PC
Cable	DDS to TX	
	2CH RX to ADC	
	Ethernet interface to host computer	Radar data for main DSP or host PC for map
Host PC	Radar data and map	Operate radar

Table 1 FMCW Sensor/Radar Basic Parts and Key Function List

3. 24GHz FMCW Front End

3-1: Photo and Draw of Front end

Fig 3 is the photo and design draw with outlet size of 24GHz FMCW front end. The unit is in inch.

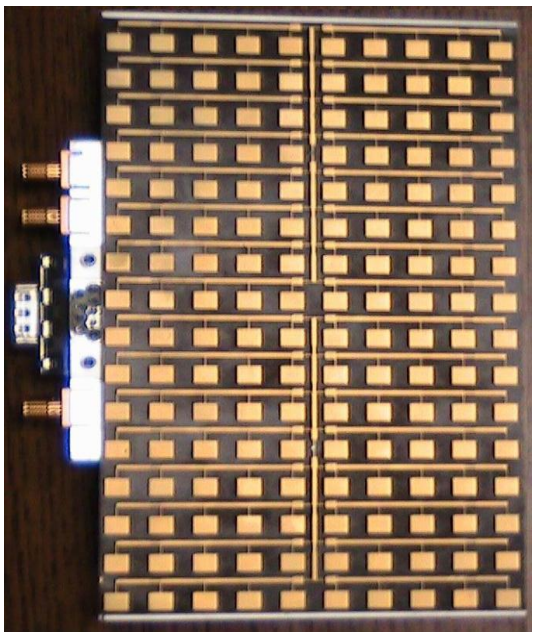

Fig 3-1 Antenna Photo

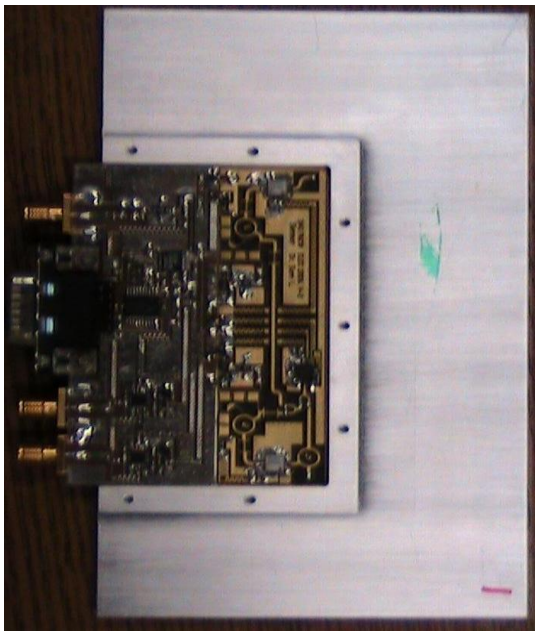

Fig 3-2 Transceiver Photo

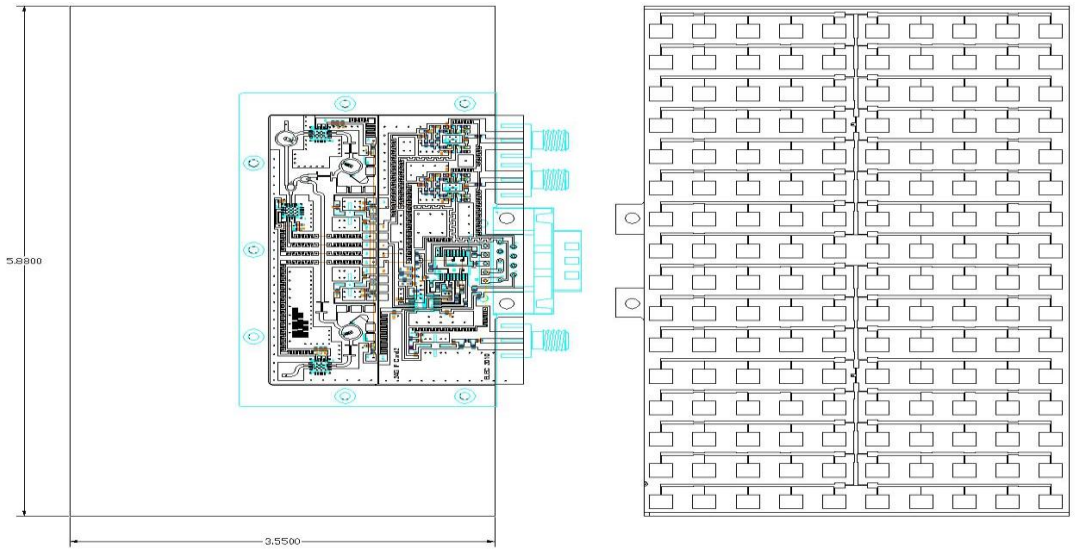

Fig 3-3 Antenna and Transceiver Design draw and outlet size in inch

3-2: 24GHz FMCW Radar Diagram Block

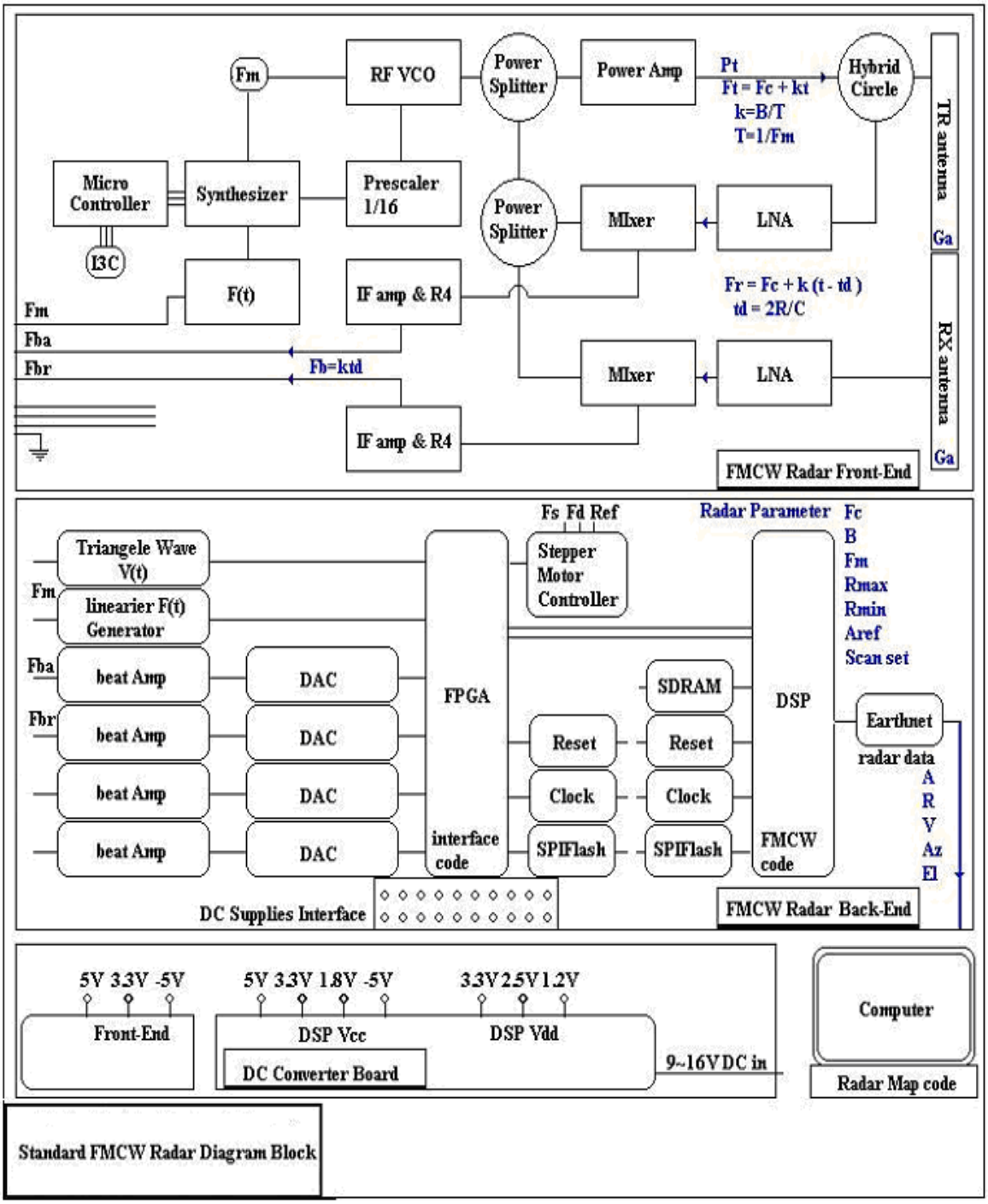

Fig 4 24GHz FMCW Radar Diagram Block

3-3: TX Frequency Setup

As shown in Diagram Block of 24GHz FMCW radar, micro controller inside the front end, and DSP core of back-end sets TX parameters.

TX parameters are center frequency fo, swept band B, and modulation frequency Fm.

The TX of 24 GHz front end is a 24GHz VCO locked by a synthesizer, which is operated by a micro controller. A 16 prescaler is used to divide 24GHz frequency down to 1.5GHz so that synthesizer can process. The maximum Phase Detector Frequency Fpdf of synthesizer is 250MHz. The minimum divider number for VCO frequency is 24. The DSP can provide any frequency band between 10~210MHz with 0.05% linearity FMCW signals in 10KHz stepper frequency.

The fo and B from PLL set maybe different with design value. The order of set rule are: 1) let tolerance of B as small as better. Most set can reach tolerance is zero. 2) let tolerance of fo smallest, 3) let Fpdf as high as better for lower phase noise issue.

Fo and B can be adjusted by the requirement from customer to customer. Typical fo range is from 23.4GHz to 24.2GHz. The value of B is from 10MHz up to 1GHz. (maximum of fo is less than 23.8GHz when 1GHz band required). Anyway, they are not changed after ELEC pre-set.

The waveform of swept band is triangle wave in frequency-time plane. Then the modulation frequency Fm is default as 1KHz. It can be adjusted as 0.25, 0.5, 1, 2, 4, 5, 8, and 10KHz if customer wants upgrade. The limitation of parameter set is maximum sample frequency of ADC is 2.5MHz each CH for 2 ADC CHs. So that maximum fb [fb=(4BFm/C)Rmax + fdmax] should be less than 1.25MHz.

TX of 24GHz FMCW radar default set are: B=200.00MHz, fo=24.12533GHz, Fpdf=60.3125MHz. Then DSP provides 180.19~181.69MHz FMCW signals to TX of front end. The maximum detect range is 200m. The Doppler frequency is 161Hz for 1m/sec. Then max range return frequency is 533.3KHz. Maximum Doppler frequency is less than 10KHz (if maximum relative velocity is 140mph). They are inside the limitation 1.25MHz.

4. Front-end only User Manual

4-1: Requirements List

Standard product	
Radar Front-end	ELEC™ 24GHz FMCW Front-end
Cable	DB9-to-Banana Plugs cable (for 5V, 3V, -5V) 3 SMA to SMA Cables (For Fm, fbr, and fba)
Customer have	
Power Supply	Capability to generate 5V/500mA, 3V/500mA, and –5V/200mA
Function Generator	Capability to generate any frequency range inside 10~210MHz Triangle wave in F-T plane, -9dBm/50ohm, 0.05% linearity, 1 or 10KHz stepper.
Measurement	Spectrum analyzer (this manual recommended) or customer PC which has FMCW DSP function

4-2: Setting Up the FMCW Front-end

1) Connecting the **Radar front-end** with the **DB9** side of the cable.
2) Connecting the **Banana plugs** of the cable with power supply and provide 5V/500mA, 3V/500mA and –5V/200mA DC to **radar front-end**.
3) Connecting SMA cable between Fm and the **Function generator**. Set function generator fstart=180.19MHz, fstop=181.69MHz. and select triangle wave form. (Or the value agreement before delivers). The power is –8+/-1dBm for 50ohm load.
4) Connecting the **Spectrum analyzer** with SMA cables named the **"FBA"** or **"FBR"** port of the cable.
5) Turn on DC supplies. Note 5V DC supply should be the first one for turn. It is the best turn all 3 DC supplies at the same time.

4-3: Check front-end Works by Spectrum Analyzer

The frequency of fb signal is equal to (4BFm/C)R+/-fd. Where fd=2Vd/(C/fc). C is light velocity, 3x10^8m/sec. Vd is target velocity; R is the distance of the target. At 24GHz carrier, fd=161Hz when target radial velocity is 1m/s. It is much smaller than range frequency. Spectrum Analyzes test is just for static target (because spectrum analyzer has no FMCW process function. It only has DAC and FFT function). So the return frequency is 2.667KHz per meter. When B=200MHz, Fm=1KHz. In other words, read spectrum analyzer output frequency, then divided by 2.667, it is the range of the target.

The amplitude should be larger than –70dBm (march ELEC back-end sensitivity). The signal to noise ration is 10dB or higher.

If customer has FMCW DSP, or host PC to process FMCW radar signal, the connection is referred to the follow section.

5. Front-end With Back-end User Manual

5-1: Requirements

Front-end work with ELEC DSP back-end is the FMCW sensor. It output radar data thru USB interface to host DSP or host PC. The radar data contact all information of targets. The detail radar data parameters are (Amplitude, Range, Velocity, Azimuth angle, …)$_j$, j=1, 2,……N. the maximum N is inter number of Rmax/range resolution as long as target amplitude is larger than Amplitude threshold (typical is –70dBm). For example, Rmax=200m, dR (range resolution) is 1m, radar maximum radar data will include 200 targets, each target has at least 4 parameters. Radar data are digit store in memory inside DSP or host PC.
To use the FMCW sensor, requirements parts are listed

Fundament parts	
Radar Front-end	ELEC™ 24GHz FMCW front-end **24G-T1R2-WS-WB2** (refer fig 2)
Radar Back-end	ELEC™ DSP board
Cables	DB9-to-DB9 cable, Ethernet cable. 3 SMA to SMA
Optional parts	
Power Supplies	Capability to generate 9V/600mA, 5V/500mA, -5V/200mA, 3V/500mA
Host computer	Check radar data

5-2: Setting up the FMCW Sensor

1) Connecting the **Radar front-end** and **back-end** with the **DB9-to-DB9 cable**. And 3 SMA Cables
2) Connecting the **back-end DSP box Banana plugs** to DC power supplies 9V, 5V, 3V, and –5V.
3) Connecting the back-end DSP box USB interface to host computer
4) Turn on all DC supplies. If not turn on in the same time. Turn on 5V before turn on 3V.
5) Check radar data on host computer

6. 24GHz FMCW Radar User Manual

6-1: Requirement

FMCW Radar sensor only output radar data. It is hard for operator to operate the radar, or see target by eye. With the help of host computer and radar map code, FMCW radar brown host PC screen and key broad to run the radar, and recorder all radar data. Follow is the list parts for FMCW radar

Fundament parts	
Radar Front-end	ELEC™ 24GHz FMCW front-end : **24G-T1R2-WS-WB2** (refer fig 2)
Radar Back-end	ELEC™ DSP board
DSP User CD	ELEC FMCW radar map code
Cables	DB9-to-DB9 cable, Ethernet cable. 3 SMA to SMA
Optional parts	
Power Supplies	Capability to generate 9V/600mA, 5V/60mA, -5.5V/30mA, 5V/60mA dc
Host PC	
Operating System	Windows® XP
Processor	Pentium® 4 2.0G or better
Memory	2GB or better
Software	Matlab® 7.0 (ELEC just provide trial version in 45days)

6-2: Setting Up the FMCW Radar

Setup Matlab 7.0

1) Copy **X**:\ code\Matlab\tcp_udp_ip to **C:\MATLAB7\work.**
2) Double click icon **MATLAB7** on desktop to launch matlab.
3) Click **…** and set Current Directory to **C:\MATLAB7\work\tcp_udp_ip**
4) Type **radar** in **Command Window**, and press **ENTER** to launch radar map program.

Setup Web

5) Connect DSP board with computer using **Ethernet cable.**
6) Right click **My Network Places** and select **Properties** in order to open **Network Connections**.
7) Right click **Local Area Connection** and select **Properties.**
8) Select **Internet Protocol(TCP/IP) -> Properties.**
   On the Internet Protocol(TCP/IP) Properties page, select **Use the following IP address**, and set the **IP address** as **192.168.1.77**, set **Subnet mask** as **255.255.255.0**. And then click **OK** to save the configuration.

Setup FMCW Radar

Connect the **Radar front-end** and **back-end** with the **DB9-to-DB9 cable**. And 3 SMA Cables

Connecting the **back-end DSP box Banana plugs** to DC power supplies 9V, 5V, 3V, and –5V.

Connecting the back-end DSP box USB interface to host computer by USB cable

Turn on all DC supplies. If not turn on in the same time, turn on 5V before turn on 3V

6-3: Operate FMCW Radar

1) After DSP board and front-end is turned on, open the **internet browser** on computer and type http://192.168.1.11/index.html, then Radar Operate Parameter Window appears for user to adjust radar parameters, as Fig 5 shows.

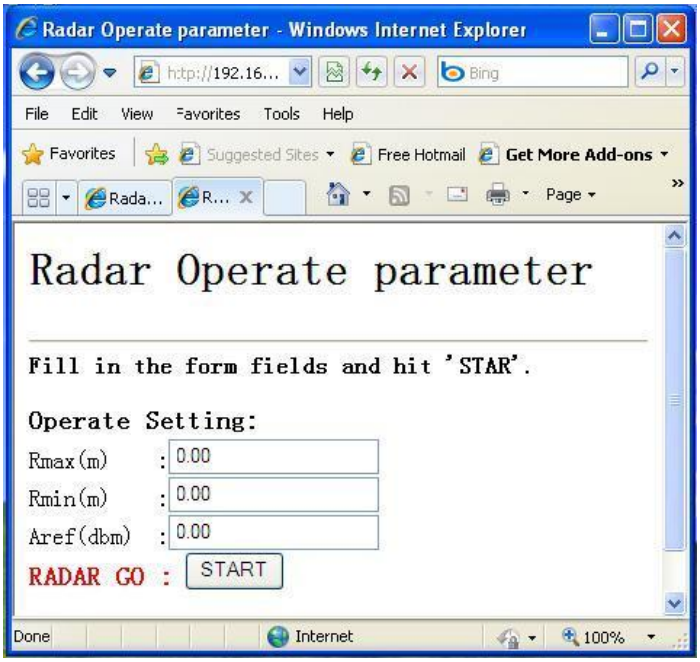

Fig 5 Radar Operate Parameter Window

2) For radar data, Rmin=0m, Rmax=200m, and Aref=-70dBm. As mentioned before, radar data will recorder all targets which amplitude larger than –70dBm. And range is from 0 to 200m. Because of the range resolution is 1m, so that maximum targets in radar data is 200. Radar map will zoom range window by reselect Rmain and Rmax, as long as 0 <= Rmin <Rmax <= 200m. Beside of it, radar map will filter less important target by reselect Aref. (-70dBm <= Arfef <-10dBm). Input radar parameters then click "**START**" button to save the configuration and turn the radar front-end on.
3) Launch Matlab® 7.0. Set folder "**tcp_udp_ip**" as Current Directory, then type command: **radar** to run radar map program.
4) When the radar map program comes out (as Fig 6 shows), the 24GHz FMCW radar system will be ready to use.

6-4: Test Set and Record FMCW Radar Data

6-4-1: Outdoors Set

Test Photo shown in Fig 1 sets Aref=-60dBm. Rmin=0m, and Rmax=150m. This set is for ELEC outdoor test field, which maximum range is 150m.

6-4-2: Indoor Set

Test photo shown in Fig 6 sets Aref=-35dBm, Rmin=0m, and Rmax=15m. This set is for ELEC indoor test field, which maximum range is 13.5m when door closed. The target is set at 6m.

6-4-3: Zoom for outdoors Set

Test photo shown in Fig 7, zoom outdoor test field for Rmin=0m, Rmax=50m, and Aref=-60dBm. One person is stand at 35meters and left offset of antenna beam. A truck is parked at 44meter and right offset of antenna beam. Mono-pulse radar map is selected to show photo clearly.

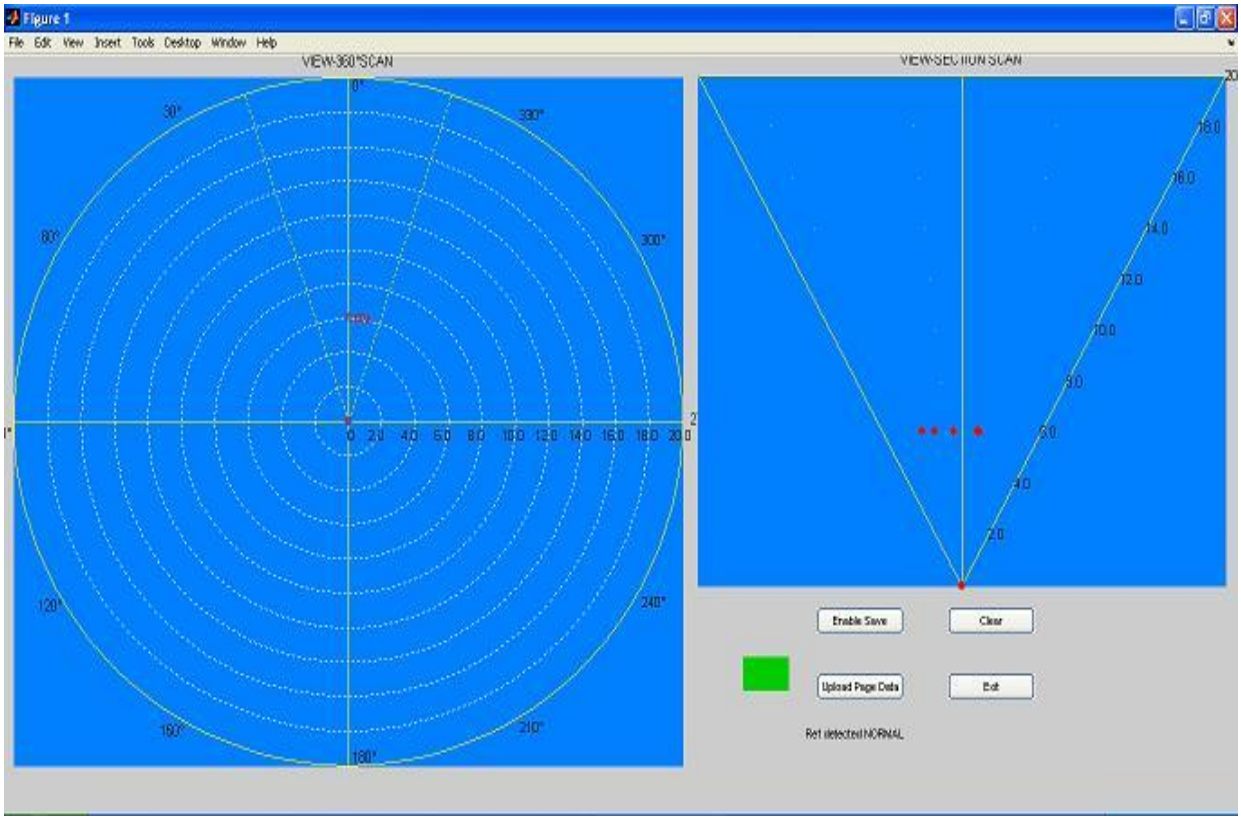

Fig 6 Radar Map and Operate Key

6-4-4: Function of Radar map Operate Key

There are 4 operate keys on Radar display screen. They are: (Fig 7 has clear picture)

1) **Exit** key: press exit will end radar map display.
2) **Enable Save** key: Press enable save key will save radar data in text-format to file named **runfmcw**. Operator can fid this file in follow patch **C:\Matlab7\work\tcp_udp_ip\runfmcw.**
   The radar data will be saved page by page as long as memory size is larger enough or exit key is pressed.
3) **Clear** Key: press Clear will clear all data stored in **runfmacw** file. Operator must rename runfmcw if they want keep old test data.
4) **Upload Page Data** Key. Press this key code will record radar data and stored them to file named **fmcw**. Operator can fid this file in follow patch **C:\Matlab7\work\tcp_udp_ip\fmcw.** This file only store last 15 pages of radar data. And fresh them when page number is increased. It is required to press stop key show in Fig 5. (Note, Fig 5 RADAR GO in red color indicates start, after press start it changes to stop, which means radar is run and waiting stop.) Then read last 15 page of radar data in **fmcw** file.

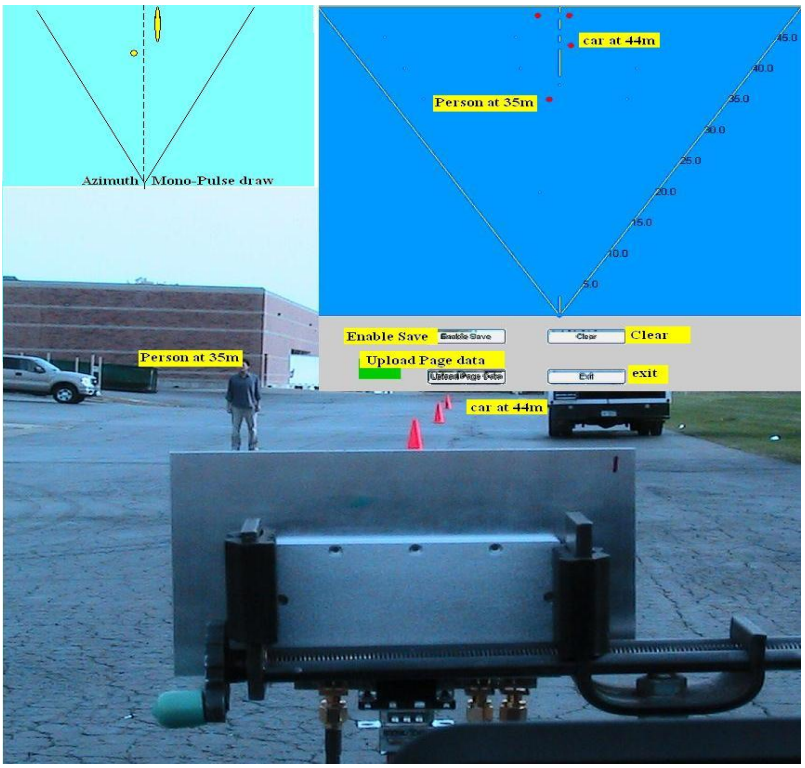

Fig 7 Person at 35m with Truck at 44~48m, both offset antenna maximum beam line

6-4-5: Radar Data Format

ELEC FMCW radar code generates Fm signal for TX. DSP finish ADC convert and FFT twice for each Fm period. The rule to select target is compare FFT signals amplitude with Aref. When Fm=1KHz, DSP analyzes return signal every 0.5ms. So it gets positive slop and negative slop frequency in 1ms, and future convert them as range, and velocity with amplitude parameters. Because DSP process 2CHs, compare their phase get mono-pulse angle. Default is in Elevation plan. For Azimuth mono-pulse radar, just process EL parameter as Az parameter. ELEC FMCW code still has ability to drive stepper motor for mechanical scan. Default is in Az plane. So Az plane has 3 choice, fixed beam (with or without mono-pulse), 360 scan, and sector scan.
Anyway, Code sees target/targets 1 time in 1 Fm period. Code will see target Nc times and average them together as radar-data-cell in Nc of Fm period. Usually Nc>=5. For mechanical scan, each Az angle, typical is stepper motor stepper, 1.8 degrees, has 1 radar-data-cell. 1 complete scan generates radar-data. So there are 200 radar-data-cells in one page of radar-data. The number of radar-data-cell is scan range/1.8. The code set 50ms as upgrade time for no scan model. In other words, Nc=50 when Fm=1KHz. So that radar-data-cell is equal to 1 page of radar-data only for no scan model.

Page /	Range [m]	Pred_Range [m]	Vel [m/s]	Level [dB]	Az [deg]	El [deg]	Time [s]
**********							
**********							
The total number of target:10							
1	8.258595e+000	8.256050e+000	-5.088806e-002	-4.429640e+001	0.000000e+000	-4.644889e-002	-1.622894e+002
1	1.242343e+001	1.241894e+001	-8.979797e-002	-5.762337e+001	0.000000e+000	-4.543343e-003	-1.383487e+002
1	2.359644e+001	2.362646e+001	6.004333e-001	-5.566792e+001	0.000000e+000	-4.292140e-002	3.929902e+001
1	4.667752e+001	4.668222e+001	9.399414e-002	-5.277904e+001	0.000000e+000	1.715591e-001	4.966003e+002
1	5.536511e+001	5.536569e+001	1.159668e-002	-4.118474e+001	0.000000e+000	5.581319e-001	4.774221e+003
1	7.850197e+001	7.864035e+001	2.767639e+000	-6.168728e+001	0.000000e+000	-1.092745e+000	2.836423e+001
1	9.797610e+001	9.788319e+001	-1.858215e+000	-6.264806e+001	0.000000e+000	5.726362e-002	-5.272591e+001
1	1.164773e+002	1.162358e+002	-4.829102e+000	-6.529134e+001	0.000000e+000	1.593266e+000	-2.411987e+001
1	1.866552e+002	1.867376e+002	1.646729e+000	-6.771371e+001	0.000000e+000	-1.917515e-001	1.133491e+002
1	1.948862e+002	1.948799e+002	-1.245117e-001	-3.996028e+001	0.000000e+000	5.756488e-001	-1.565203e+003
**********							
**********							
The total number of target:9							
2	8.257847e+000	8.260359e+000	5.023956e-002	-4.428306e+001	0.000000e+000	-9.197966e-002	1.643694e+002
2	1.242235e+001	1.254273e+001	2.407570e+000	-5.744363e+001	0.000000e+000	-1.145791e-004	5.159707e+000
2	2.356006e+001	2.352744e+001	-6.524658e-001	-5.544279e+001	0.000000e+000	1.834682e-002	-3.610926e+001
2	4.667465e+001	4.667085e+001	-7.598877e-002	-5.267740e+001	0.000000e+000	2.331109e-001	-6.142309e+002
2	5.536811e+001	5.536304e+001	-1.014709e-001	-4.116022e+001	0.000000e+000	5.191031e-001	-5.456548e+002
2	7.849271e+001	7.847962e+001	-2.618408e-001	-6.166935e+001	0.000000e+000	-1.105290e+000	-2.997726e+002
2	9.796005e+001	9.790948e+001	-1.011353e+000	-6.271648e+001	0.000000e+000	-1.351163e-002	-9.686044e+001
2	1.865963e+002	1.868374e+002	4.820557e+000	-6.752603e+001	0.000000e+000	-4.108958e-002	3.870847e+001
2	1.948824e+002	1.948898e+002	1.483154e-001	-3.985904e+001	0.000000e+000	5.751307e-001	1.313973e+003
**********							

Fig 8 Radar Data Format

One typical radar data is shown in Fig.8. It gives 2 pages of no scan radar-data. Each page tells how many target radar detect. Let just analyzes page 1. It list the page number in 1st row . Then give the **Range** from 8.3m to 194.9m in 2nd row, follow the **Pred Range** in 3rd row, which means the predict range next time (after 50ms) radar see them again. It cones from current range and velocity Vel at row 4. Most of them is static target (-5cm/s, -9cm/s, 0.6m/s, 9cm/s, 11cm/s and –12cm/s). Part of them has velocity at (2.8m/s, -1.8m/s, -4.8m/s, and 1.6m/s). The 5th row gives target amplitude from –40dBm to –65dBm, all of them are larger than –70dBm. The 6th row is Az angle. Because no scan, all of them is at 0 degree. The 7th row is El angle. The last row is time predict when target touch radar. The negative means target is moving away from radar. The danger is the target moving forward radar. Target 6 will touch radar after 28 seconds.

7. Typical 24GHz Radar Specification

	Sign	Unit	Value Range	Recommend
Front End				
Transmit power	Pt	dBm	6~8	
Carrier frequency	Fc	GHz	24.125+/-0.0005	Fm must be F(t)
Swept Band	B	MHz	200 up to 1GHz	default If license approved
Modulation	Fm	KHz	1~10	1KHz default
Waveform			triangle wave	
Linearity	L	%	0.05	Fm=F(t)
Antenna Type			Dual patch array	In Azimuth-direction
Antenna Gain	G	dB	23~24	
Azimuth 3db beam	Az	degree	10.4+/-0.8	
Elevation 3dB beam	El	degree	8.2+/-0.5	
Side lobe	Aside	dB	16~25	
Isolation	Iso	dBc	>50 10~20	RX only TR share 1 antenna
Receiver Noise	N	dB	3~4	
Dynamic range	DR	dB	60~80	With 12 bit ADC
Size	LxWxH	inch	5.9x3.8x0.52	
Weight		g	<300	
DC supply	V/I	V/A	5V/0.5A, 3V/0.5A, -5V/0.2A	Current rate is 1A
Interface			DB9, and SMA	
Back End				
Fm frequency		KHz	0.25, 0.5, 1, 2, 4, 5, 8, 10	1KHz default
Freq/time function	Fm [F(t)]	MHz	Any range between 10~210	0.05% linearity
DAC sample Freq	fsamp	MHz	2.5/1.25/0.625	2CH
FFT bit			128/256/512	512 default
Scan Model			Fixed beam 360 deg scan +/-(18, 36, 45, 90) sector	Fixed beam default
Scan rate	Fs	Hz	0.1,0.25,0.5,1,2,2.5,4,5	1Hz default
Scan stepper	Ss	deg	1.8	
Target number			16 for fixed beam 4 for each 1.8 deg stepper	Just for radar map
Interface			DB9 with SMA Ethernet to PC DC connector	
Typical Radar Spec				
Max range	Rmax	m	Human 30~50 Car: 100~200	
Min range	Rmin	m	0~Rmax-1	
Range resolution	dR	m	1m (B=200MHz)	0.2m (B=1GHz)
Max velocity	Vmax	M/s	60	
Velocity resolution	dV	M/s	1	Optional to 0.2~0.5